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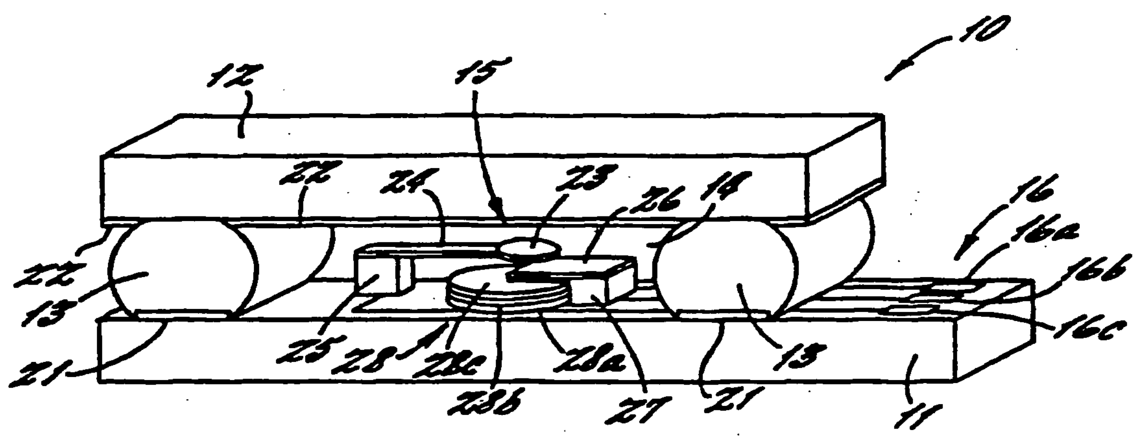

(57) Abstract

A micro-relay module includes a substrate and a lid in spaced apart relation, and a solder ring which bonds the lid to the substrate to define a chamber therebetween. A micromachined relay is integrally formed on the substrate or on the lid within the chamber. A gas is contained in the chamber at a gas pressure which is above atmospheric pressure. Input/output pads are included outside the chamber and electrically connected to the micromachined relay. Large numbers of encapsulated modules may be fabricated on a single substrate by integrally forming an array of relays on a face of a first substrate. A second substrate is placed adjacent the face with a corresponding array of solder rings therebetween, such that a respective solder ring surrounds a respective relay. The solder rings are reflowed in a gas atmosphere which is above atmospheric pressure to thereby form an array of high pressure gas encapsulating chambers. The first and second substrates are then singulated for from a plurality of individual micro-relay modules.

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ENCAPSULATED MICRO-RELAY MODULES AND METHODS OF FABRICATING SAME

Field of the Invention

This invention relates to microelectronic devices and modules and more particularly to microelectronic relay devices and modules, and methods of fabricating same.

Background of the Invention

Relays are widely used as switching devices. For example, the telecommunications industry uses relays for many switching applications, at a current market value of approximately $500 million per year. Mechanical relays are highly developed commodity products. An example of a conventional mechanical relay is the NAIS TK Ultralow Profile 2 Amp Polarized Relay. Relays are often encapsulated with a high pressure gas. See U.S. Patent 4,168,480 to De Lucia.

Microelectromechanical systems (MEMS) have recently been developed as alternatives for conventional electromechanical devices such as relays. MEMS devices are potentially low cost devices, due to the use of microelectronic fabrication techniques. New functionality may also be provided because MEMS devices can be much smaller than conventional electromechanical devices. A MEMS relay, also referred to herein as a micro-relay or a micromachined relay are described in publications entitled *"An Electrostatically Actuated Micro-Relay"* by Drake et al., The 8th International Conference on Solid-State Sensors and Actuators, and Eurosensors IX, Stockholm, Sweden, June 25-29, 1995, pp. 380-383; *"Thermally Controlled Magnetization Microrelay"* to Hashimoto et al., The 8th International Conference on Solid-State Sensors and Actuators, and Eurosensors IX, Stockholm, Sweden, June 25-29, 1995,

pp. 361-364; *"Electromagnetic Linear Actuators With Inductive Position Sensing for Micro Relay, Micro Valve and Precision Positioning Applications"* by Guckel et al., The 8th International Conference on Solid-State Sensors and Actuators, and Eurosensors IX, Stockholm, Sweden, June 25-29, 1995, pp. 324-327; *"Electromagnetic Microrelays: Concepts and Fundamental Characteristics"* by Hosaka et al., Sensors and Actuators A, Vol. 40, 1994, pp. 41-47; and *"Rugged Design for Reliable Switching: Micro A Relay Sets New Automotive Standards"* by Knuppel, Siemens Components (English Edition), Vol. 29, No. 4, July-August 1994, pp. 30-32, the disclosures of which are hereby incorporated herein by reference.

Micro-relays have heretofore made few inroads in the conventional mechanical relay market. The primary reasons for lack of market penetration appear to be cost and performance. As to cost, even though conventional relays may require coil winding and assembly operations, the mature market and off-shore assembly of conventional mechanical relays has maintained a low cost. As to performance, telecommunications relays typically must provide a high breakdown voltage of about 2000 volts or more, so as to withstand a direct lightning strike. A long lifetime and vibration resistance must also generally be provided. In view of the higher cost and lower performance of micro-relays, their market penetration presently continues to be small.

Summary of the Invention

It is therefore an object of the present invention to provide improved micro-relays and methods of fabricating same.

It is another object of the present invention to provide low cost micro-relays and methods of fabricating same.

It is another object of the invention to provide high performance micro-relays and methods of fabricating same.

These and other objects are provided, according to the present invention, by a micro-relay module which includes a substrate and a lid in spaced apart relation, and a solder ring which bonds the lid to the substrate to define a chamber therebetween. A micromachined relay is integrally formed on the substrate or on the lid, within the chamber. A gas is contained in the chamber at a gas pressure which is above atmospheric pressure. The gas contacts the micromachined relay. A plurality of input/output pads are included outside the chamber, and electrically connected to the micromachined relay.

According to the invention, a bonded solder ring may be used to enclose high pressure gas at pressures of up to 20 atmospheres or more in the chamber. Because the chamber is small, the structure can contain the high pressure gas. The high pressure gas greatly increases the breakdown voltage of the relay, to about 5000 volts or more. Moreover, the high pressure gas may also reduce sputter degradation which is a major failure mechanism of relays. The inherent reliability of a micromachined relay provides excellent vibration resistance and an extended lifetime. Accordingly, high performance micro-relay modules may be provided.

In one embodiment of the present invention, a micromachined relay is integrally formed on a face of the substrate within the chamber, and the input/output pads are formed on the substrate face outside the chamber. The substrate includes means for electrically connecting the micromachined relay to the input/output pads, using surface or buried wiring. Alternatively, the micromachined relay may be integrally formed on a face of the lid within the chamber and the micro-relay

modules includes means, within the chamber, for electrically connecting the micromachined relay to the substrate. In a preferred embodiment, solder bumps within the chamber, extending between the substrate and the lid, may be used to electrically connect the micromachined relay on the lid to the substrate.

The lid and substrate may both include solder wettable bonding sites thereon so that the solder ring is bonded to the wettable bonding sites. Preferably, the wettable bonding sites and/or the solder ring are pretreated with a fluorine-containing plasma so that soldering may be performed without the use of the flux. The cavity is thereby rendered free of any residual flux which could degrade the performance and lifetime of the micro-relay. The micromachined relay may be fabricated using conventional MEMS manufacturing techniques.

Active microelectronic circuits may also be included in the micro-relay module. Preferably, if the micromachined relay is integrally formed on one of the substrate and the lid, the active microelectronic circuits are integrally formed on the other of the substrate and the lid, so that MEMS devices and conventional microelectronic circuits may be formed on different substrates.

It will be understood that the substrate, lid, solder ring, high pressure gas and input/output pads may be used to form a MEMS module including MEMS devices other than relays. Such a MEMS module may also be expected to have high breakdown characteristics and thereby overcome breakdown problems of many conventional MEMS devices.

Large numbers of encapsulated MEMS modules maybe fabricated on a single substrate according to the present invention, to thereby reduce manufacturing cost and make MEMS modules competitive with conventional electromechanical modules. In particular, a MEMS

module is formed by integrally forming an array of MEMS devices on a face of a first substrate. A second substrate is placed adjacent the face with a corresponding array of solder rings therebetween, such that a respective solder ring surrounds a respective MEMS device. The solder rings are reflowed in a gas atmosphere which is above atmospheric pressure to thereby form an array of high pressure gas encapsulating chambers for the array of MEMS devices. The first and second substrates are then singulated to form a plurality of individual MEMS modules. Low cost, high performance MEMS modules are thereby fabricated.

The solder bonding step may take place by bonding the array of solder rings to the second substrate and placing the second substrate adjacent the face of the first substrate with the bonded array of solder rings therebetween. Alternatively, the solder rings may be bonded to the face of the first substrate, and the second substrate may be placed adjacent the face with the bonded array of solder rings therebetween. In yet another alternative, solder ring preforms may be placed between the first and second substrates, and then simultaneously bonded to both faces. The reflowing step is preferably preceded by the step of performing a fluxless plasma pretreatment on the solder rings, so that the reflow takes place without flux. Accordingly, high performance is maintained.

Brief Description of the Drawings

Figure 1 is a perspective view of a first embodiment of a micro-relay module according to the present invention.

Figure 2 is a perspective view of a second embodiment of a micro-relay module according to the present invention.

Figure 3A is a cross-sectional view of a micro-relay module of Figure 1 during a first intermediate fabrication step.

Figure 3B is a cross-sectional view of a micro-relay module of Figure 1 during a second intermediate fabrication step.

Detailed Description of Preferred Embodiments

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, the thickness of layers and regions are exaggerated for clarity. Like numbers refer to like elements throughout.

Figure 1 is a perspective view of a first embodiment of a micro-relay module according to the present invention. As shown in Figure 1, micro-relay module **10** generally includes a substrate **11** and a lid **12** in spaced apart relation. A solder ring **13** bonds the lid to the substrate to define a chamber **14** therebetween. A micromachined relay **15** is integrally formed on the substrate **11** within chamber **14**. A plurality of relays may also be formed within chamber **14**, or one or more relays and others MEMS devices may

be formed within chamber **14**. Gas is contained in chamber **14**, at a gas pressure which is above atmospheric pressure. The gas contacts the micromachined relay. Finally, a plurality of input/output pads **16** on the substrate **11** outside chamber **14** are electrically connected to the micromachined relay **15**. The electrical connectors may include an insulating layer thereon, to prevent the solder ring 13 from shorting the connectors to one another.

Details of the micro-relay module **10** will now be described. Substrate **11** may be a monocrystalline silicon substrate, a glass substrate or any other substrate which is conventionally used for microelectronic or MEMS applications. As shown in Figure 1, substrate **11** includes a bonding region **21** in the form of metallization or other conventional solder wettable material, for bonding to solder ring **13**. Alternatively, in order to define a bonding region, solder dams **22** may be used as shown on lid **12** if the lid is a solder wettable material. The fabrication of solder bonding regions and solder dams to confine solder on a substrate is well known to those having skill in the art and need not be described further herein.

Solder ring **13** bonds lid **12** to substrate **11**. The solder ring 13 may be circular, rectangular, square, polygonal or of any other shape. Conventional lead-tin solder may be used. Other solder formulations may also be used. In other applications, the bonding may take place using brazing, gluing or other known bonding techniques. Preferably, the bonding is sufficiently strong so as to contain a gas in the chamber **14** formed thereby, at greater than atmospheric pressure, preferably in the range from 10 to 20 atmospheres, to thereby increase the breakdown voltage of relay **15**, which is enclosed within chamber **14**.

Relay **15** may be formed by conventional MEMS techniques which need not be described in detail herein. In general, relay **15** includes a pole piece **23**, a first relay contact comprising conductive cantilever (bending beam) **24** and first support **25**, and a second relay contact **26** on second support **27**. The relay magnet **28** may include a field concentrator **28a**, an insulator **28b** and a coil **28c**. Also contained on substrate **11** are input/output pads **16**. Three contact pads **16a**, **16b** and **16c** are shown. However, it will be understood that more or fewer pads may be provided. As shown in Figure 1, third input/output pad **16c** is electrically connected to first relay contact **24**. Second input/output pad **16b** is electrically connected to second relay contact **26**, and first input/output pad **16a** is electrically connected to a relay magnet **28**. The electrical connectors may include an insulating layer thereon, to prevent the solder ring **13** from shorting the connectors to one another.

The relay materials and dimensions, and the high pressure gas in chamber **14** may be selected to prevent electrical breakdown between the relay contacts **24** and **26** of up to 5000 volts or more. For example, a 25μm gap between pole piece **23** and second relay contact **26** may withstand more than 5000 volts in 20 atmospheres of SF_6 as illustrated by the Paschen curves which are reproduced in Figure 4. Other gases such as nitrogen may be used. However, they may only be able to withstand lower voltages.

Figure 2 illustrates an alternate embodiment **10'** of micro-relay module **10**. In contrast with Figure 1, relay **15** is formed on lid **12**. In order to electrically connect relay **15** with input/output pads **16** on substrate **11**, solder bumps, two of which are shown in Figure 2, may be used. For example, solder bump **17a** electrically connects the second relay contact **26** with pad **16a**. Solder bump **17b** electrically connects the

first relay contact **24** with the second pad **16b**. A third solder bump may be required to contact the relay magnet **28** with the third solder I/O pad **16c**. It will be understood that other connecting means can be used instead of solder bumps. However, solder bumps are particularly amenable to formation at the same time that solder ring **13** is bonded.

As also illustrated in Figure 2, substrate **11** includes active microelectronic circuits **18** therein. These microelectronic circuits may include microprocessors, controllers, memory devices, drivers and other conventional microelectronic circuits. Due to the generally differing processing requirements of microelectronic circuits **18** and micromachined relay **15**, it may be preferable that they be formed on different substrates. Accordingly, in Figure 2, microelectronic circuits **18** are formed in substrate **11** and micromachined relay **15** is formed on lid **12**. However, these devices may also be formed on the same substrate. Finally, in the embodiment of Figure 2, bonding regions **21** and **21'** are in the form of wettable rings. Solder dams need not be used. It will also be understood that one or both of the bonding regions may be unpatterned, i.e. the entire substrate may be covered with, or formed of, solder wettable material.

Referring now to Figures 3A and 3B, a method of fabricating a plurality of micro-relay modules **10** of Figure 1 will now be described. It will be understood by those having skill in the art that methods according to the present invention may also be used to fabricate a plurality of MEMS modules which includes MEMS devices other than relays, such as motors, actuators and the like. For ease of explanation, Figures 3A and 3B illustrate the parts of Figure 1 in schematic form, and eliminate many details of relay **15**.

Figures 3A and 3B illustrate only three modules **10a**, **10b** and **10c** which are formed

simultaneously. However, it will be understood by those having skill in the art that typically many more modules are formed simultaneously. For example, on 4" wafers, up to 4,000 or more modules may be formed simultaneously in an array.

Referring now to Figure 3A, an array of MEMS devices **10a-10c** are formed on a face of a first substrate **11'**. An array of input/output pads **16** is also formed on face **11a** of substrate **11'**.

The fabrication of MEMS devices are well known to those having skill in the art and need not be described in detail herein. However, the fabrication of a MEMS relay **15** as illustrated in detail in Figure 1, will be briefly described. Face **11a** of substrate **11'** may first be patterned to form the lines which connect the relay parts to the input/output pads **16**. A photopatterning sequence may be performed on an oxidized silicon wafer to produce a liftoff mask with reentrant sidewall profiles. A metal stack may then be additively deposited using evaporation. The metal stack may be a Ti/Al/Pd stack to provide adequate adhesion to the substrate, high current capacity and a seed layer for plating and wire bonding capabilities.

The next element of the micro-relay to be fabricated is the relay electromagnet **28**. The field concentrator **28a** is located beneath the coil **28c** and is formed of a magnetic material such as Ni or permalloy. Insulator **28b** may be formed of silicon nitride or other insulating materials using plasma enhanced chemical vapor deposition. Vias may be etched in this material to provide contact with the underlying metal pattern. A planar coil **28c**, formed for example of Cu, may then be deposited using standard liftoff processes. This metal deposition step may also be used to form the bonding region **21** for the solder ring **16**. A thick dielectric layer may then be deposited and appropriately etched to form first support **25**. A via

may be etched through the first support and filled, so that electrical contact may be made. Plating may be used to fill the via. Metal may then be deposited on the dielectric to form the first and second relay contacts **24** and **26** respectively.

Once the bottom of the relay is formed, a gap between the contacts is formed. The gap may be formed by coating a very thick polymer layer such as photoresist. The conductive cantilever **25** may be patterned and formed on the thick polymer layer using Ni plating. An Au/Ti/Ni/Ti/Au structure may be formed. Other metallurgies may be used. Then, the polymer layer may be removed using a release process to form a freestanding cantilever. Other well known MEMS processes may be used to form relays or other MEMS devices, as is well known to those having skill in the art.

Still referring to Figure 3A, second substrate **12'** is fabricated separately. Underbump metallurgy may be deposited in a blanket layer to serve as a current path for electroplating the solder rings **13**. The top surface of the underbump metallurgy may be a nonwettable metal that is patterned in the shape and size of the base of the seal for the solder ring. A photoresist template may then be patterned to provide a large volume region for the ring to be plated with solder. The solder may then be reflowed and the field metal etched. It will be understood by those having skill in the art that other embodiments may initially form the solder rings on substrate **11'** rather than substrate **12'** as illustrated. In yet other embodiments, solder preforms may be formed and inserted between substrates **12'** and **11'** prior to reflow. It will also be understood that a plurality of individual substrates, with or without solder rings, may be picked and placed in spaced apart relation to a large substrate, and reflowed.

In a preferred embodiment of the present invention, the first and second substrates **11'** and **12'** including the MEMS device **15** and the solder rings therebetween are then placed adjacent one another in the direction shown by arrows **31** as illustrated in Figure 3B. A high pressure reflow is then performed to encapsulate SF_6, N_2 or other gases in the chambers. Reflow may take place at 250°C for eutectic lead-tin solder, for example, but high lead content solder may be preferred for compatibility with subsequent assembly processes.

In the preferred embodiment of the present invention, a fluxless solder treatment is performed prior to or simultaneous with, reflow. Fluxless solder treatment insures that flux is not used in the process and will not remain in chambers **14**. It will be understood that residual flux in chambers **14** could have a deleterious effect on the operation and reliability of the micro-relay module **10**.

A preferred fluxless soldering process exposes the solder rings **13** and/or pads **21** or **21'** to a fluorine-containing plasma and reflows the solder as described in detail in U.S. Patent 4,921,157 entitled *"A Fluxless Soldering Process"* to Dishon et al. and assigned to the assignee of the present invention, the disclosure of which is hereby incorporated herein by reference. Fluorine plasma pretreatment may be accomplished in an apparatus described in U.S. Patent 5,499,754 entitled *"Fluxless Soldering Sample Pretreating System"* to Koopman et al. and assigned to the assignee of the present invention, the disclosure of which is hereby incorporated herein by reference. Reflow may then take place in a system **35** that can accommodate a high pressure gas such as SF_6.

Finally, referring to Figure 3B, the first substrate **11'** and the second substrate **12'** are singulated to thereby produce the individual micro-

relay modules. As shown in Figure 3B, first cuts **32** are made in substrate **11'** and second cuts **33** are made in substrate **12'** in order to form substrate **11** and lid **12** (Figure 1) respectively. It will be understood that the first and second cuts may be made simultaneously using laser cutting, saws, dicing or any other known technique. In order to expose input/output pads **16**, a third cut is made in substrate **12'** to remove portions **12a** of substrate **12'**. The micro-relay module **10** may then be wire bonded and encapsulated in a conventional plastic package or other package. The micro-relay module can provide plug compatible replacements for existing relays.

Micro-relay modules fabricated as described above may provide improved performance at reduced cost. In particular, a high breakdown voltage and high operating lifetime may be provided at a cost which may be a fraction of a conventional mechanical relay.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

CLAIMS:

1. A micro relay module comprising:

a substrate and a lid in spaced apart relation;

a solder ring which bonds said lid to said substrate to define a chamber therebetween;

a micromachined relay integrally formed on one of said substrate and said lid, within said chamber;

gas in said chamber, at a gas pressure which is above atmospheric pressure, and contacting said micromachined relay; and

a plurality of input/output pads outside said chamber, and electrically connected to said micromachined relay.

2. A micro relay module according to Claim 1 wherein said micromachined relay is integrally formed on a face of said substrate within said chamber, and wherein said plurality of input/output pads are formed on said substrate face, outside said chamber.

3. A micro relay module according to Claim 2 wherein said substrate further comprises means for electrically connecting said micromachined relay to said input/output pads.

4. A micro relay module according to Claim 1 wherein said micromachined relay is integrally formed on a face of said lid within said chamber, and wherein said micro relay module further comprises means, within said chamber, for electrically connecting said micromachined relay to said substrate.

5. A micro relay module according to Claim 4 wherein said electrically connecting means comprises

a plurality of solder bumps within said chamber, extending between said substrate and said lid.

6. A micro relay module according to Claim 1 wherein each of said substrate and said lid include a solder wettable bonding site thereon, and wherein said solder ring bonds said solder wettable bonding sites to one another.

7. A micro relay module according to Claim 1 wherein said chamber is free of solder flux therein.

8. A micro relay module according to Claim 1 wherein said substrate includes a substrate extension region which extends beyond said lid, and wherein said input/output pads are located in said substrate extension region.

9. A micro relay module according to claim 1 wherein at least one of said lid and said substrate further includes active microelectronic circuits.

10. A micro relay module according to Claim 9 wherein said micromachined relay is integrally formed on one of said substrate and said lid, and wherein said active microelectronic circuits are integrally formed on the other of said substrate and said lid.

11. A microelectromechanical system (MEMS) module comprising:

a substrate and a lid in spaced apart relation;

a solder ring which bonds said lid to said substrate to define a chamber therebetween;

a MEMS device integrally formed on one of said substrate and said lid, within said chamber;

gas in said chamber, at a gas pressure which is above atmospheric pressure, and contacting said MEMS device; and

a plurality of input/output pads outside said chamber, and electrically connected to said MEMS device.

12. A MEMS module according to Claim 11 wherein said MEMS device is integrally formed on a face of said substrate within said chamber, and wherein said plurality of input/output pads are formed on said substrate face, outside said chamber.

13. A MEMS module according to Claim 12 wherein said substrate further comprises means for electrically connecting said MEMS device to said input/output pads.

14. A MEMS module according to Claim 11 wherein said MEMS device is integrally formed on a face of said lid within said chamber, and wherein said MEMS device further comprises means, within said chamber, for electrically connecting said MEMS device to said substrate.

15. A MEMS module according to Claim 14 wherein said electrically connecting means comprises a plurality of solder bumps within said chamber, extending between said substrate and said lid.

16. A MEMS module according to Claim 11 wherein each of said substrate and said lid include a solder wettable bonding site thereon, and wherein said solder ring bonds said solder wettable bonding sites to one another.

17. A MEMS module according to Claim 11 wherein said chamber is free of solder flux therein.

18. A MEMS module according to Claim 11 wherein said substrate includes a substrate extension region which extends beyond said lid, and wherein said input/output pads are located in said substrate extension region.

19. A MEMS module according to claim 11 wherein at least one of said lid and said substrate further includes active microelectronic circuits.

20. A MEMS module according to Claim 19 wherein said MEMS device is integrally formed on one of said substrate and said lid, and wherein said active microelectronic circuits are integrally formed on the other of said substrate and said lid.

21. A micro relay module comprising:

a substrate and a lid in spaced apart relation;

means for bonding said lid to said substrate to define a chamber therebetween;

a micromachined relay integrally formed on one of said substrate and said lid, within said chamber;

gas in said chamber, at a gas pressure which is above atmospheric pressure, and contacting said micromachined relay; and

a plurality of input/output pads outside said chamber, and electrically connected to said micromachined relay.

22. A micro relay module according to Claim 21 wherein said micromachined relay is integrally formed on a face of said substrate within said chamber,

and wherein said plurality of input/output pads are formed on said substrate face, outside said chamber.

23. A micro relay module according to Claim 22 wherein said substrate further comprises means for electrically connecting said micromachined relay to said input/output pads.

24. A micro relay module according to Claim 21 wherein said micromachined relay is integrally formed on a face of said lid within said chamber, and wherein said micro relay module further comprises means, within said chamber, for electrically connecting said micromachined relay to said substrate.

25. A micro relay module according to Claim 24 wherein said electrically connecting means comprises a plurality of solder bumps within said chamber, extending between said substrate and said lid.

26. A micro relay module according to Claim 21 wherein said chamber is free of solder flux therein.

27. A micro relay module according to Claim 21 wherein said substrate includes a substrate extension region which extends beyond said lid, and wherein said input/output pads are located in said substrate extension region.

28. A micro relay module according to claim 21 wherein at least one of said lid and said substrate further includes active microelectronic circuits.

29. A micro relay module according to Claim 28 wherein said micromachined relay is integrally formed on one of said substrate and said lid, and wherein said active microelectronic circuits are

integrally formed on the other of said substrate and said lid.

30. A microelectromechanical system (MEMS) assembly comprising:

a substrate and a lid in spaced apart relation;

an array of solder rings between said lid and said substrate, which bond said lid to said substrate to define an array of chambers therebetween;

an array of MEMS devices integrally formed on one of said substrate and said lid, a respective at least one of which is enclosed in a respective one of said chambers;

gas in said chambers, at a gas pressure which is above atmospheric pressure, and contacting the MEMS device in the chamber; and

an array of an input/output pads outside said chambers, a respective one of which is electrically connected a respective at least one of said MEMS devices.

31. A MEMS assembly according to Claim 30 wherein said array of MEMS devices is integrally formed on a face of said substrate within said chambers, and wherein said array of input/output pads is formed on said substrate face, outside said chambers.

32. A MEMS assembly according to Claim 31 wherein said substrate further comprises means for electrically connecting respective ones of said MEMS devices to respective ones of said input/output pads.

33. A MEMS assembly according to Claim 30 wherein said array of MEMS devices is integrally formed on a face of said lid within said chambers, and wherein said MEMS assembly further comprises means, within said

chambers, for electrically connecting respective ones of said MEMS devices to said substrate.

34. A MEMS assembly according to Claim 33 wherein said electrically connecting means comprises at least one solder bump within each of said chambers, extending between said substrate and said lid.

35. A MEMS assembly according to Claim 30 wherein each of said substrate and said lid include an array of solder wettable bonding sites thereon, and wherein said solder rings bond said solder wettable bonding sites to one another.

36. A MEMS assembly according to Claim 30 wherein said chambers are free of solder flux therein.

37. A MEMS assembly according to Claim 30 wherein at least one of said lid and said substrate further includes active microelectronic circuits.

38. A MEMS assembly according to Claim 37 wherein said MEMS devices are integrally formed on one of said substrate and said lid, and wherein said active microelectronic circuits are integrally formed on the other of said substrate and said lid.

39. A method of fabricating a plurality of microelectromechanical system (MEMS) modules comprising the steps of:

integrally forming an array of MEMS devices on a face of a first substrate;

placing a second substrate adjacent said face with a corresponding array of solder rings therebetween, a respective solder ring surrounding a respective MEMS device;

reflowing said solder rings in a gas atmosphere which is above atmospheric pressure, to thereby form an array of high pressure gas encapsulating chambers for said array of MEMS devices; and

singulating said first and second substrates to form a plurality of individual MEMS modules.

40. A method according to Claim 39 wherein said integrally forming step comprises the step of integrally forming an array of MEMS devices and an array of input output/pads on said face.

41. A method according to Claim 39 wherein said placing step comprises the steps of:

bonding said array of solder rings to said second substrate; and

placing said second substrate adjacent said face, with the bonded array of solder rings therebetween.

42. A method according to Claim 39 wherein said placing step comprises the steps of:

bonding said array of solder rings to said face; and

placing said second substrate adjacent said face, with the bonded array of solder rings therebetween.

43. A method according to Claim 39:

wherein said reflowing step is preceded by the step of performing a fluxless plasma treatment on said solder rings; and

wherein said reflowing step comprises the step of reflowing said solder rings without using flux.

44. A method according to Claim 39:

wherein said integrally forming step comprises the step of integrally forming an array of MEMS devices and an array of input output/pads on said face, with the array of input/output pads being located on said face in spaced apart relation to the corresponding array of MEMS devices, such that said input/output pads lie outside said array of solder rings; and wherein said singulating step comprises the steps of:

cutting said first substrate around each corresponding group of MEMS devices and input/output pads; and

cutting said second substrate twice around each ring, to allow separation of individual second substrates and to expose said input/output pads.

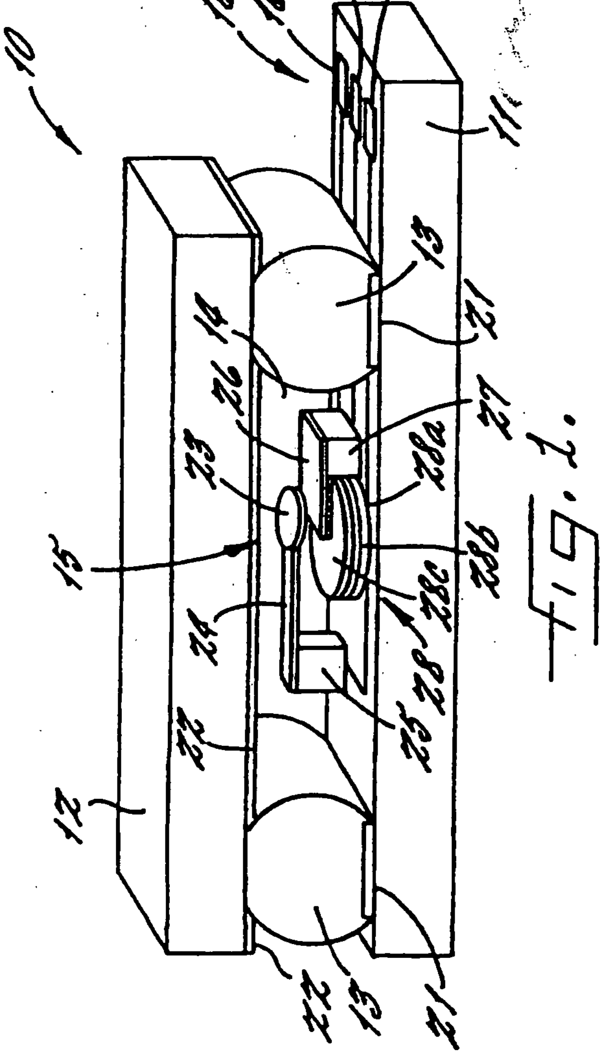
10
16
16a
16b
16c
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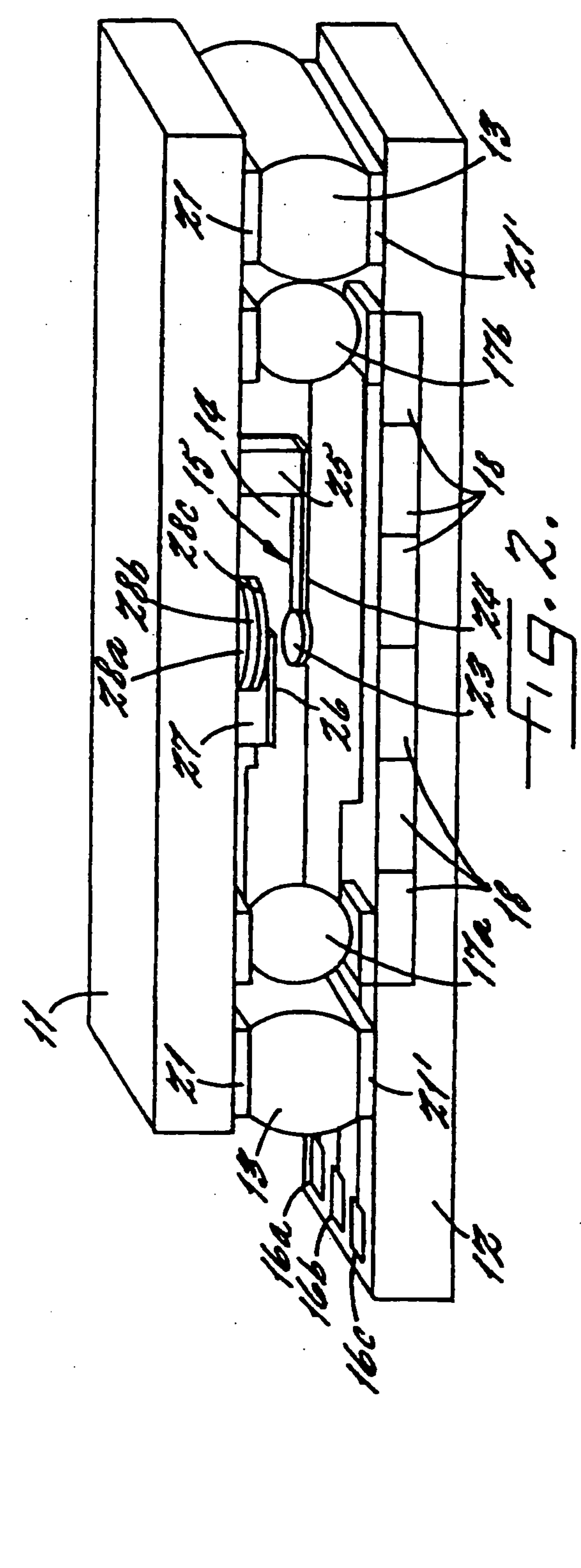
FIG. 1.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21'
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16b
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12

FIG. 2.

FIG. 3A.

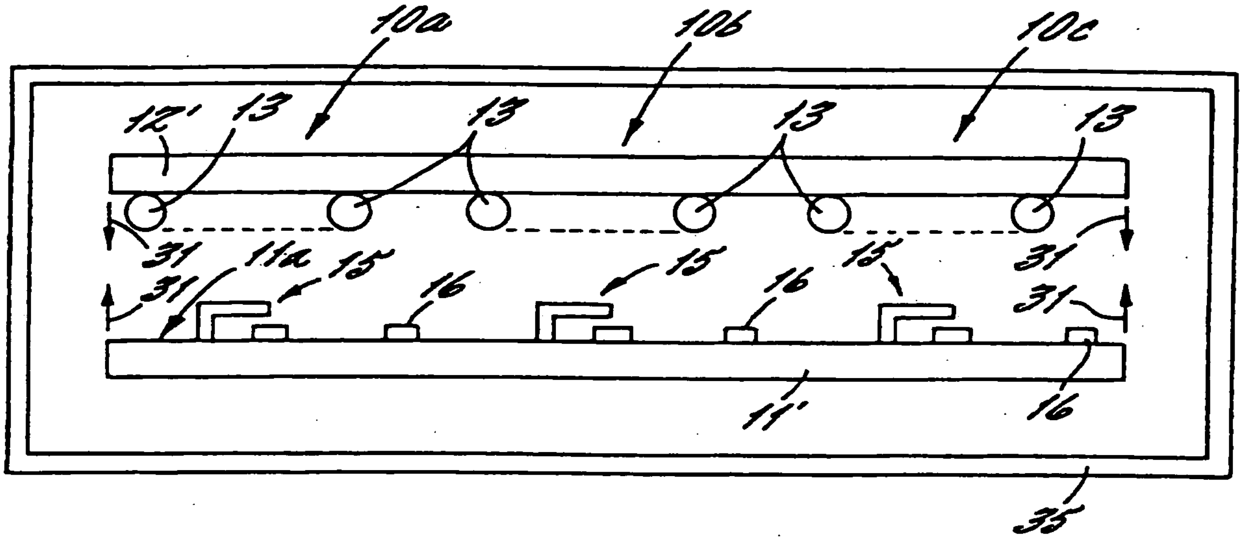
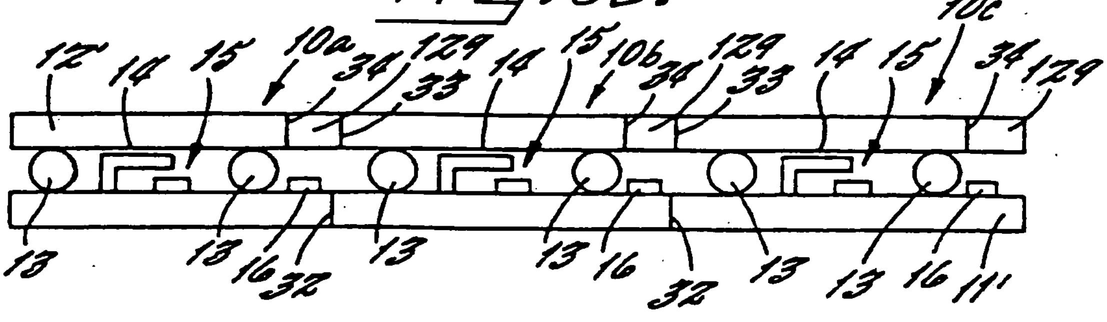


FIG. 3B.



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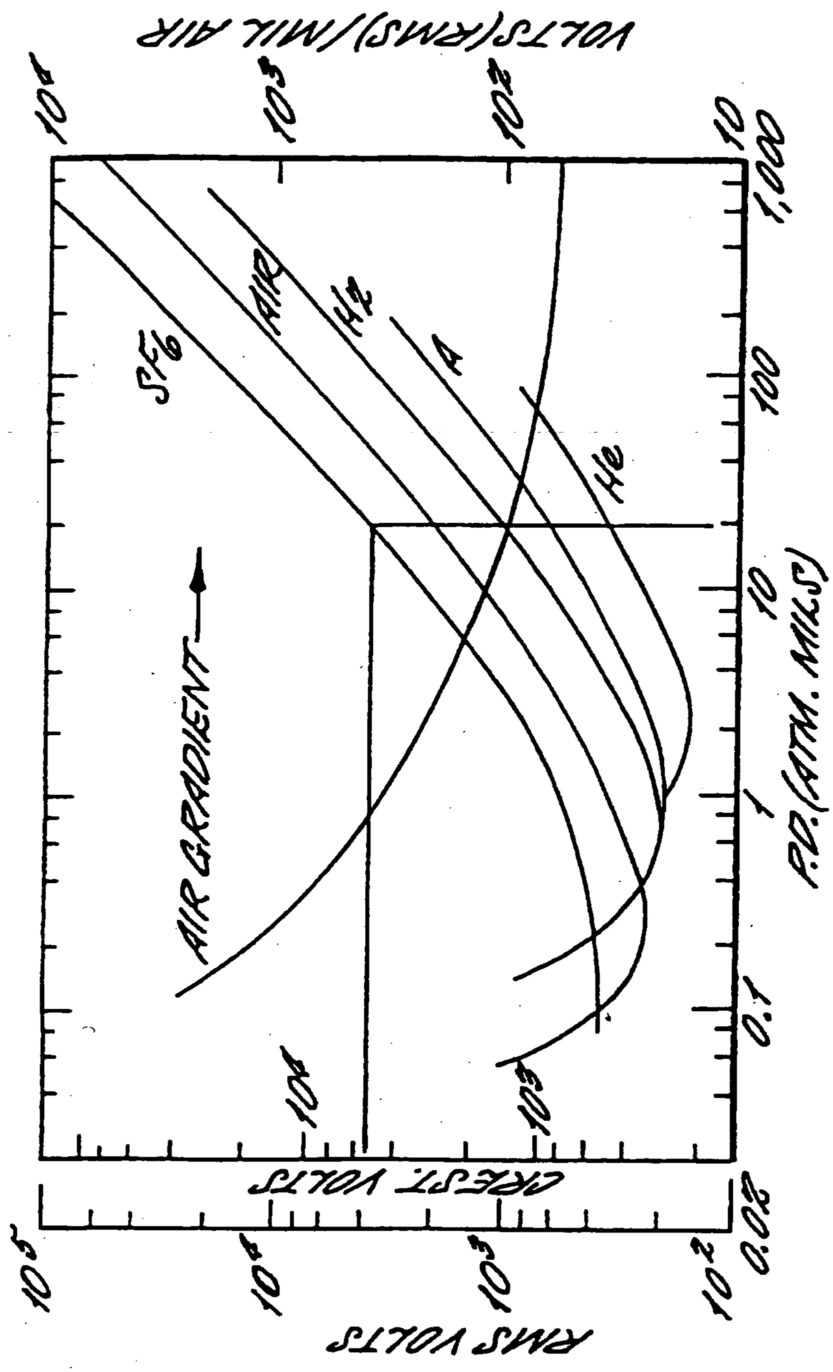
VOLTS(RMS)/MIL AIR
10⁴
10³
10²
10
SF6
AIR
H2
A
He
AIR GRADIENT
1,000
100
10
1
0.1
0.02
P.D.(ATM. MILS)
10⁴
10³
CREST. VOLTS
10⁵
10⁴
10³
10²
RMS VOLTS

FIG. 4.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/14332

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01H1/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 42 05 029 C (SIEMENS AG) 11 February 1993 see column 3, line 18 - line 42 see column 6, line 19 - line 25 see figure 2	1-44
A	DE 43 23 799 A (TOSHIBA KAWASAKI KK) 20 January 1994 see column 10, line 42 - column 11, line 5 see figure 2	1-44
A	US 4 168 480 A (DE LUCIA VICTOR E) 18 September 1979 cited in the application see column 1, line 1 - line 12	1-44

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of mailing of the international search report
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Authorized officer
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 257 905 A (CHRISTOPHOROU LOUCAS G ET AL) 24 March 1981 see column 3, line 15 - line 32 see figure 1	1-44

1

INTERNATIONAL SEARCH REPORT

formation on patent family members

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PCT/US 97/14332

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